How climate change influences the disease burden: the case of meningitis in northern Benin and malaria in Zimbabwe.

The African Climate Change Fellowship Program

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1.0 Introduction

The health implications of climate change has received less attention than some other sectors, but play a key role in ensuring that developmental gains and progress with regards to health and wellbeing continue within the context of a changing climate.
The location-specific manifestations of climate change determine the interactions with, and likely effects on, disease prevalence. The prevalence of infectious diseases (malaria, meningitis, trypanosomiasis, fever) and those related to water (cholera, dysentery)could experience a resurgence through a greater possibility of reproduction of different vectors (mosquitoes, flies etc.)(Boko et al., 2007).

The paper takes two case study examples to investigate the effects of climate change on health: meningococcal disease and meningitis in Benin, and malaria in Zimbabwe. After elaborating the specific nature of the relationships, a number of recommendations are made in order to reduce the occurrence of these diseases, and any increase that might be brought about by climate change. It addresses the grand challenge of "What kind of institutional innovations are required to advance development goals and improve the resilience of vulnerable communities in Africa so that they are more able to cope with current and future climate variability and change?" In both cases, integrating the identified climate variables that affect disease prevalence into surveillance systems would allow early warning to reduce vulnerability to these diseases.

2.0 Climate and meningitis in Benin

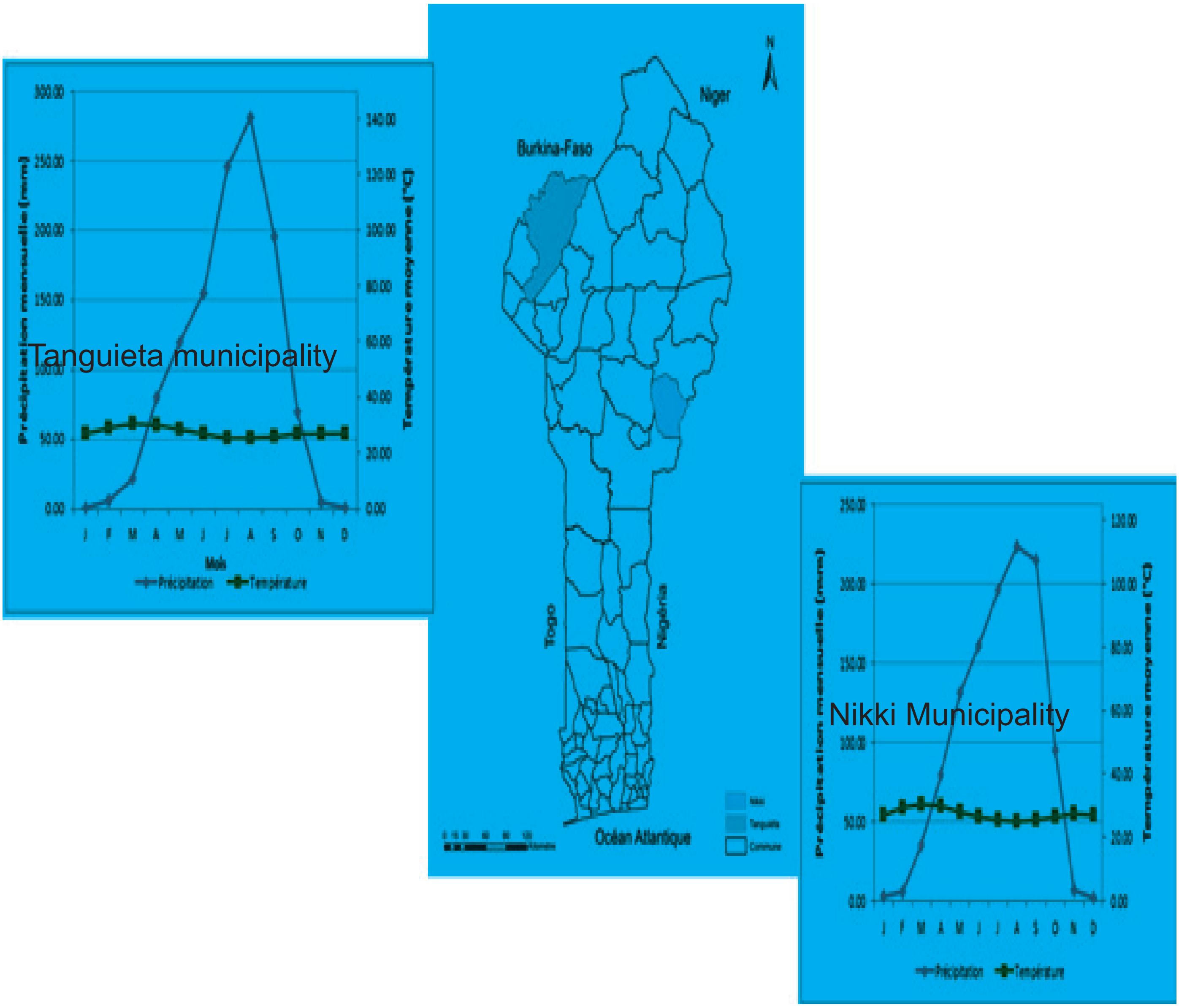
Almost all scientific studies suggest links between climatic and environmental factors in the occurrence and prevalence of meningococcal disease, and outbreaks of meningitis (Rémy, 1990; Moore, 1992; Oke, 1994; Besancenot et al., 1997;

Molesworth et al., 2003; Sultan et al 2004.; Bouma et al., 2012). Whilst viral meningitis is more benign, cerebrospinal meningitis is an infection caused by the bacterium Neisseria meningitidis, which leads to inflammation of the meninges, and can cause death within hours. After the onset of symptoms, including severe headache and stiff neck, rapid clinical examination is required, which involves lumbar puncture to test the spinal fluid. With rapid treatment adults can make a full recovery, although numerous and various complications may affect a third of those affected by the disease.

Meningitis is highly contagious and transmitted by air. As a result, it is an epidemic-prone disease that currently threatens 300 million people in Africa. Many epidemics have affected the continent, particularly sub-Saharan Africa, since the 1980s (Varaine et al., 1997; Molesworth, 2003).

The "African meningitis belt" widens depending on the time of year and associated conditions, stretching from Senegal to Ethiopia, whilst Benin, Burkina Faso and Chad are often severely affected (Lapeyssonnie, 1963). Benin has a warm and humid climate. The monsoon, which is a moist wind from the southwest, brings rain, and the northeast trade winds dominate during the long dry season. Meningitis is endemic to northern Benin.

Figure 1 : Location of the two municipalities and their climate characteristics



2.1 Method

The study combined modeling and primary fieldwork to determine the impacts of climate change on the prevalence of cerebrospinal meningitis. A stepwise process was used to identify the municipalities that are most affected by meningitis. Four of Benin's 12 departments in the northeast of the country - Borgu, Alibori Atakora and Donga were scrutinised and the two most affected municipalities were Tanguiéta (Atakora) and Nikki (Borgu). With a Sudano-Guinean climate, Nikki is characterized by a long rainy season (April to October) and a long dry season (November to March). During the dry season, the harmattan, a hot dry wind, blows from the northeast leading to a sharp decline in the relative humidity at the beginning of December. Tanguiéta's climate is Sudano-Sahelian. The rainy season runs from May to November, peaking in August and September, and a dry season from November to May.

The dry season is subdivided into two parts: the harmattan from November to February where the diurnal temperature is large, followed by a high heat until May (figure 1). Tanguiéta is the focal point of the meningitis epidemic in Benin.

Modelling was conducted to identify the major trends and identify correlations between climate and the occurrence of meningitis in Benin. Data sets for the period 1983-2012 were taken from the Agency for the Safety of Air Navigation in Africa and Madagascar (ASECNA) and the World Health Organization (WHO), supplemented by epidemiological data from the National Institute of Statistics and Economic Analysis (INSAE), the Ministry of Health, and county health departments (DDS) of Borgu-Alibori and Atacora-Donga. Climate data on the different variables identified as explanatory factors for the occurrence of meningitis, namely rainfall, temperature, relative humidity and wind speed were also used (Molesworth, 2003; Sultan, 2005).

Social data was also obtained from survey questionnaires collected from 150 respondents. , including 30 public health specialists (epidemiologists and physicians) and 120 people in vulnerable communities (40% men and 60% women aged from 27 to 76 years), which were used to elicit perceptions on the correlation between climate and meningitis based on a five point scale of seriousness of various climate variables. Four focus groups (two in each community) also took place to analyse the effectiveness of response strategies across a Likert scale, and direct observation of meningitis cases as identified by hospitals in the study areas to explore patient perceptions.

To analyse the data, a log-linear regression was performed with statistical data on the Eviews 3.1 software “Climginite” to estimate correlations between climatic parameters and the prevalence of meningitis in Benin.

The log model -linear estimated is as follows:

$$\text{Log (PMt)} = \alpha + \text{Log (HPT)} + \text{Log (Tempt)} + \text{Log (HRt)} + \text{Log (VVT)} + \text{error}$$

With PMt (Monthly prevalence of meningitis), HPT (The height of the rainy season); Tempt (average temperature) HRt (RH) and VVT (wind speed).

2.2 The links between climate change and meningitis

Results of the interviews with public health officials show unanimity in the belief that climate change has an impact on health, given that health is contingent upon the environment in which we exist, and that is changing. The Head of the Public Health Services Department in Atacora explained “In fact, the question of the link between health and climate is not difficult explained. Our bodies are used to a certain climate in January, another in April and this for every month of the year. But if the climate of January suddenly became that of April, the bacterium will respond and thus render us exposed to the adverse effects of climate change.” In particular, occurrences of meningitis are correlated with the dry and hot wind of the harmattan from November to February, which provides ideal conditions for airborne transmission of the bacterium.

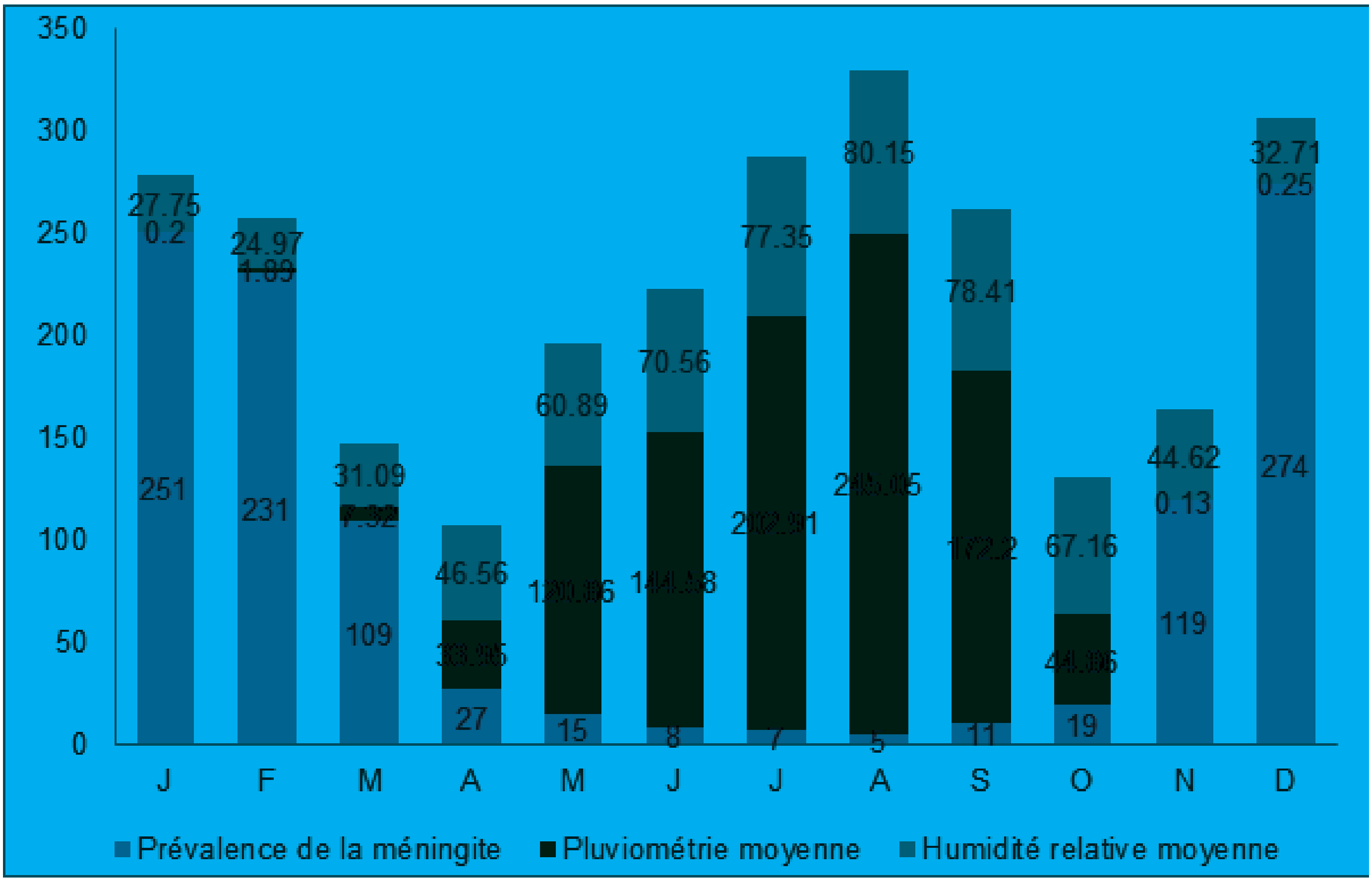
Results of the survey questionnaire showed that all of the respondents were aware of the disease, which has different names in the various local languages, the majority of which refer to the neck. 90% of respondents were able to positively identify the main symptom as a stiff neck. As with the medical experts, 91% of community members link increases in meningitis prevalence with changing environmental conditions brought about by climate change, including drought, the harmattan increased temperature, and increased presence of dust.

The empirical model confirmed the perceptions of public health professionals and communities in northern Benin regarding the positive correlation between climate and meningitis. The results of the log-linear regressions show that 91% of confirmed cases of meningococcal disease are recorded during the dry season between November and March, significant at the 1% level with ($R2 = 0\ 64$ & $p = 0.0000$) without autocorrelation ($DW = 1.69$). Climatic parameters thus explain 64% of the prevalence of meningitis in North Benin. There is an uneven monthly distribution of meningitis cases. The cases occur during the dry season between November and March when rainfall < 7.32 mm and relative humidity < 44.62%. Whilst prevalence of meningitis is positively correlated with temperature and windspeed, and negatively correlated with rainfall ($r = -0.72$, $p = 0.0113$) and relative humidity ($r = -0.65$ & $p = 0.0000$), only the negative correlations are significant at 1% (table 1 and figure 2).

Table 1: Correlation between climate variables and meningitis

Variable climatique	R	Standard Error	P. Value
Rainfall*	- 0,72	0,016	0,0113
Relative humidity	- 0,65	0,008	0,0000
Temperature	0,45	0, 852	0,2684
Windspeed	- 0, 68	0,004	0,0907
*significant variable			

Figure 2 : Temporal variation in climate parameters and their correlation with meningitis incidence



Indeed, drought and high winds, dust-laden, stimulate the Benin invasion of meningitis as noted by Besancenot et al. (1997). The moisture of the winter season greatly reduces the risk of transmission. Epidemics occur during the dry season, when the humidity is very low and dusty, and disappear during the rainy season. The epidemic season begins around November and lasts until April. During this period, over 90% of cases of meningitis are recorded in Benin. The decrease in relative humidity is a framework for the occurrence of epidemics of meningitis. This result is consistent with that obtained by Mbaye et al. (2004). They had already noticed that “the decline in the relative humidity seems to have been a necessary factor in the development of meningitis epidemics that have

“Epidemic season begins in November and lasts until April. During this period, over 90% of cases of meningitis are recorded in Benin.”

declared Niakhar between January and May 1998, 1999 and 2000.” But considering epidemic years, both individually and together, the linear correlation coefficient is negative but not significant ($p > 0.05$), and then they find that the decline in the relative humidity around the 30% threshold is not a sufficiently specific criterion because the same net decrease in relative humidity occurred quite frequently during the previous non-epidemic years. Through our approach, we concluded that the potential risk of meningitis in relatively low humidity period is significantly larger than that of the rainy season ($r = -0.65$ $p = 0.0000$ &). However, maximum temperatures and days of dust (dry, harmattan) move in the same direction in the African belt as was highlighted in several studies including those of (Remy, 1988; Mbaye et al., 2004; Sultan et al., 2004).

However, as the physician coordinator for Tanguiéta-Cobly-Matéri recognized, not everyone is vulnerable to this changing exposure in the same way, “The effects of climate change and lead to an increased vulnerability of certain groups such as children and the elderly. These have a very low capacity to adapt.”

2.3 Responses to meningitis outbreak

Responses to meningitis can be divided into categories based on who initiates them, and their timing relative to an outbreak. Exogenous strategies are those carried out by the government of Benin and international public health partners such as the World Health Organisation, whilst endogenous strategies are those that are initiated at community level.

Exogenous strategies can, in turn, be divided into two main categories: preventative, namely those that take place before an outbreak; and curative, for those responses that are actioned after an outbreak. The primary preventative exogenous strategy for dealing with meningitis is vaccinations. According to the chief of the county public health department of Borgu-Alibori, “The best strategy to prevent against meningitis is and remains vaccination. So when you are not vaccinated, you are exposed at any time”. Another critical factor that enables effective anticipation (and thus preparation) for outbreaks is to monitor disease outbreaks, and mandatory reporting of incidences is required to enable this. The Meningitis Vaccine Project detected numerous outbreaks in 2012, prompting a major vaccination campaign known as MenAfriVac. Wearing of masks to protect against the airborne bacterium, particularly in the hot, dry season, and when the harmattan creates a dusty environment, is also effective although a much less popular and less practiced response. For curing those that are already affected, the government strategy has been to publicise the imperative of hospitalisation in the case of severe headaches and neck pain.

Several strategies have been developed by communities which are both preventative and curative. Preventative strategies differ between sociolinguistic groups, but include traditional medicine (e.g. mixing pepper, water and fermented kpararou - the powdered root of a plant called tora in Bariba - and mixing sodabi-palm wine-and small lemongrass). Shea butter is also used in the nostrils since the mucous membranes are thought to contain the genes that contribute to meningitis vulnerability. Curative strategies come into play once the disease has been detected. Quarantining the patient in order to avoid contamination of the air is prevalent.

Possible correlations between the different exogenous and endogenous strategies were examined in SPSS. Two negative and two positive correlations exist at a level of significant equal to 5% (and in some cases 1%).

Preventative vaccination campaigns and the use of traditional medicines are negatively correlated at the 5% level, meaning that the more preventive vaccination campaigns are strengthened, the less people will rely on traditional medicine. Reactive vaccination campaigns and urgent hospitalisation are negatively correlated at the 5% level, meaning that the more reactive vaccination campaigns are strengthened, the less people will need urgent hospitalisation. Avoiding sandstorms during the dry harmattan season and quarantining infected individuals is also positively correlated. The same positive correlation exists at the 1% level between quarantining and resorting to traditional medicine.

Overall, the most effective strategies are curative and preventive vaccinations against meningitis and emergency hospitalization, meaning that exogenous strategies are more effective than those emerging from communities. However, as the chief of the public health department in Atacora summarised, coping strategies are not enough: “What is important in this case is the ability of humans to adapt to climate change in order to reduce the adverse health effects and prevent the consequences be. To this end, coping strategies including current strategies but also strategies to increase future capacity needs to be encouraged. Investments in the areas of health infrastructure, training, monitoring and implementation of emergency programs are not negotiable”.

3.0 Malaria in Zimbabwe

Previous studies show a close association between malaria epidemics and climate variability (Peng et al., 2003; Abeku et al., 2004; Cox and Abeku, 2007; Da Silver et al., 2007; Wandiga et al., 2010). A number of studies have attempted to develop climate-malaria transmission predictive models (Tong et al., 2008; Chaves et al., 2011; Smith et al., 2013; Tompkins and Ermert, 2013). The results of these studies show that climatic differences occur between malaria outbreak and non-outbreak months, seasons and years in those areas endemic to the disease. Several researchers have attributed the trends and variability in malaria incidences to changing rainfall, temperature, humidity and/or surface runoff (Hoshen and Morse, 2004; Briet et al., 2008; Tompkins and Ermert, 2013). Considerable evidence shows that precipitation is an important factor in the transmission of malaria (Peng et al., 2013; Smith et al., 2013; Tompkins and Ermert, 2013). Warming winter temperatures in recent years have also triggered a number of studies on the impact of seasonal temperature changes on malaria transmission, including the expansion of malaria-transmission into the East African highlands (Peng et al., 2003; Alemu et al. 2011; Chaves et al., 2011). However, temperature can only be effective in malaria transmission when it combines with favourable precipitation of surface water bodies (van Lieshout et al., 2004). Proximity to rivers and other surface water bodies has also been associated with mosquito abundance and malaria transmission in malaria endemic areas (Zhou et al., 2007), therefore hydrological modelling of river discharge is an indicator of periods when malaria outbreaks are likely (Smith et al., 2013).

In Zimbabwe malaria remains a major killer disease affecting more than 5.5 million people (Ministry of Health and Child Welfare, 2009). Gokwe North is one of the worst malaria affected dis tricts in Zimbabwe. Despite decades of attempts to control malaria using different approaches and strategies, there is no conclusive evidence on whether hydro-climatic factors are exacerbating malaria incidences in the district and how such knowledge can be used to influence policy in order to reduce the menace in communities. The aim of this study was therefore to assess the impact of hydro-climatic factors (rainfall, surface runoff and temperature) on malaria incidence, and how it is projected to change on a seasonal and inter-annual basis.

3.1 Methods

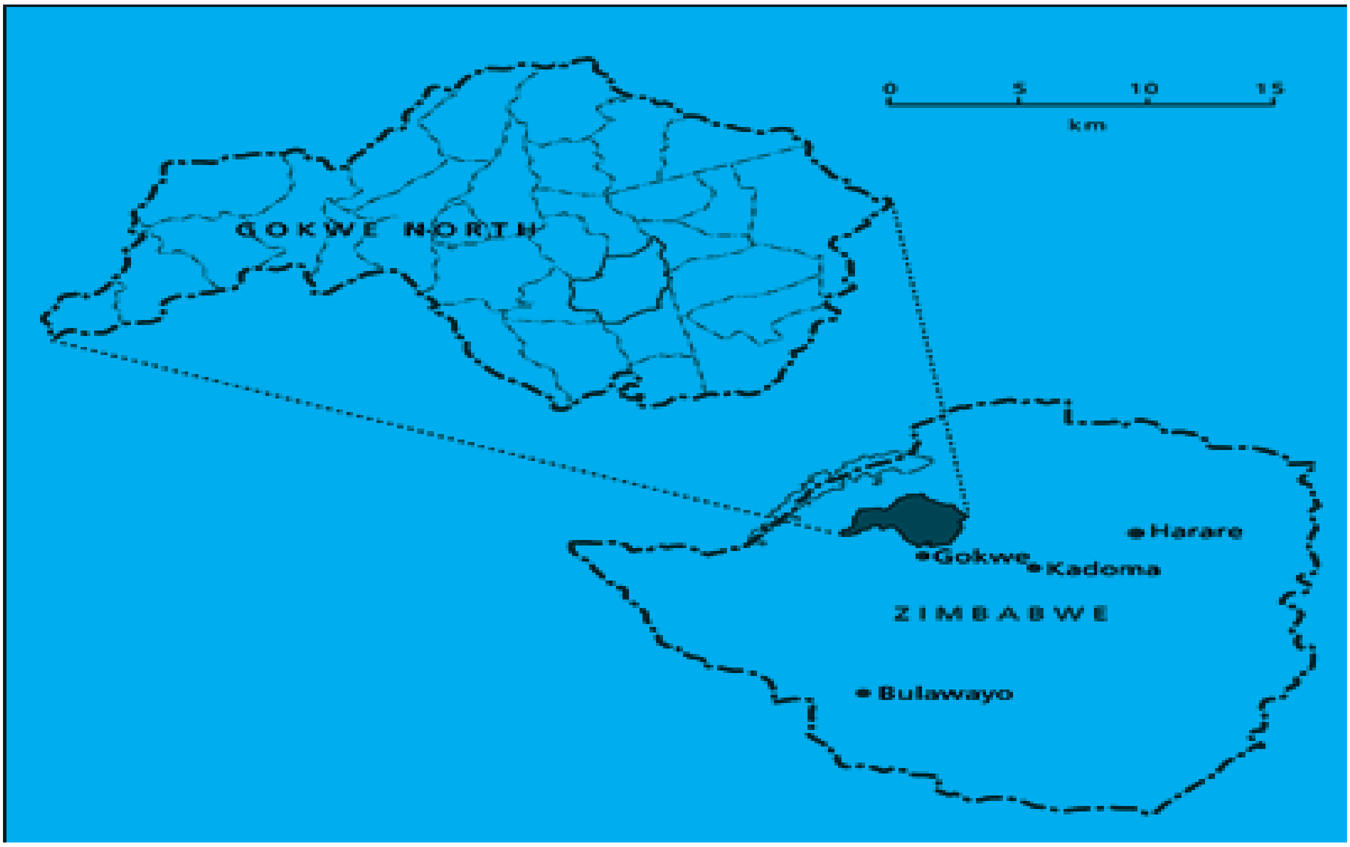
Gokwe North District lies within the Sanyati-Sengwa Basin of the Zambezi Valley, situated in the Midlands Province of Zimbabwe (Mamuse et al., 2007). The district has an area of about 7,268.09km2 and its population is approximately 244976, with 216 villages. Climatically, Gokwe North District has a warm to hot climate, with mean annual temperatures of 26°C (Mamuse et al., 2007). The district experiences two seasons, a mild to warm dry season (May to October) and a hot wet season (November to April). The district generally receives an annual rainfall of 700mm, with January being the wettest month. The biggest river flowing through the district is Sanyati River. When the river is not flowing, it forms many permanent pools (Freeman, 1993).

Malaria is endemic throughout Gokwe North District (Freeman, 1993). The main malaria transmission season is during the rainy season between November and April (Mamuse et al., 2007). Cotton growing is the main source of income for the majority of the people of Gokwe North District. The crop requires continuous weeding throughout the rain season and hand-picking throughout the winter and this undoubtedly expose people to mosquitoes, thus exacerbating the transmission of malaria in local communities (Freeman, 1993). Most villagers live far away from health amenities making early diagnosis and treatment difficult (Moyo and Zvavahera, 2004).

Historical data was collected relating to the mean monthly minimum and maximum temperature, rainfall (from the Meteorological Services Department) and surface runoff of Sanyati River (from the Zimbabwe National Water Authority) for the period 1980-2010. Data on annual malaria incidence (due to the unavailability of monthly data), defined as newly diagnosed cases per 1000 people, at station and district level was accessed from Ministry of Health and Child Welfare at provincial level for the period 1990 to 2010. Data was stored in an Access database and analysed using Stata software Version 11 (Stata Corp, College Station, TX, USA). To examine the temporal trends and variability of monthly, seasonal and annual rainfall, surface runoff and temperature, time series box and whisker plots for each variable over the period 1980–2010 were performed. The box plots reflected the periods of extreme variations such as floods or droughts over the 30 year study period. The monthly mean and standard deviations of each climate variable (rainfall, surface runoff and temperature) for the period 1980–2010 were also calculated to determine the monthly variability for each month over the study period. The impact of each hydro climatic variable on malaria incidence was assessed graphically using a straightforward time series plots with time period in years on the horizontal axis and malaria incidences on the vertical axis. The analysis considered the variability, trends and association of each hydro-climate factor with reported malaria incidence. Correlation tests were performed between malaria incidences and each of the hydro climatic variables.

Complementing information for modelling, document reviews and informal interviews with key informants (nurses, village community workers and shopkeepers) in three purposively selected wards in the district were used to assess the nature of malaria health response in terms of policy and programmes. Combining these data sources facilitated triangulation of data.

Figure 3 : Location of Gokwe North District, Zimbabwe



3.2 Hydro-climatic variation and malaria morbidity and mortality

The analysis of rainfall and surface runoff trends showed that monthly, seasonal and annual volumes decreased between 1980 and 2005 in the district. The rainfall for the summer months fluctuated showing a declining trend both monthly, seasonally and annually from 1980-2010; although the onset remained predictably unchanged and May figures fluctuated, suggesting changing duration of the rainy season. The winter rainfall was trendless and consistently low over the duration of the study period. The mean monthly surface runoff of Sanyati River was extremely sensitive to rainfall amount both monthly, seasonally and throughout the study period. The months of December to March experienced significantly higher surface runoff compared to the months May to October reflecting the seasonal influence of summer and dry seasons respectively. The surface runoff was, however, perennial.

The trend in the mean monthly and annual temperatures showed evidence of warming. The inter-annual variations of the mean temperatures showed positive trends with an average increase of between 0.3°C and 0.6°C over the 30 year study period, although there was no seasonal shift.

Malaria incidence in Gokwe North District has been fluctuating but increasing between 1990 and 2010, and this is statistically significant ($p < 0.005$). During the period 2004-2010, a total of 181,112 malaria cases were reported in the district. The annual total cases ranged from 4587 in 2010 to 59,486 in 2004, with an annual mean of 25,873 malaria cases occurring over the study period. When considering all three climatic variables together, an association between annual malaria incidences and hydro-climate variables (temperature, rainfall and surface runoff) was observed (figure 4). Rainfall in the district was seasonal and, when plotted together with malaria incidences, there was a positive, weak and significant relationship between the two ($r = 0.4$; $p< 0.005$). In extremely high rainfall years such as during the Cyclone Eline in 2000 and years of peak rainfall such as 2008, the number of malaria incidences increased to more than 40,000 in the district. Malaria incidences were similarly low during the low rainfall years such as 1992 and 2010 when the district experienced low rainfall. Given flow levels were linked to rainfall, it is not surprising that the correlation between malaria incidences and surface runoff was positive and significant ($r = 0.6$; $p<0.005$).

The correlation between annual malaria incidences and mean maximum temperature was negative and insignificant ($r = -0.3$; $p> 0.005$). Three distinct trends of malaria incidences-temperature regimes were observed. Temperatures from 20oC downwards showed a declining malaria trend (figure 5). From 20oC and 30oC malaria incidences were increasing, while maximum temperatures of more than 30°C showed malaria incidences significantly decreasing to less than 20 per 100. These differences have to do with the specific interactions between malaria vectors and people that determine malaria incidences. For cold winter seasons, malaria vectors become relatively low and the large downward trends are associated with low temperatures coupled with little rainfall.

"In extremely high rainfall years such as during the Cyclone Eline in 2000 and years of peak rainfall such as 2008, the number of malaria incidences increased to more than 40,000 in the district."

Figure 4 : The relationship between rainfall and surface runoff and malaria incidence

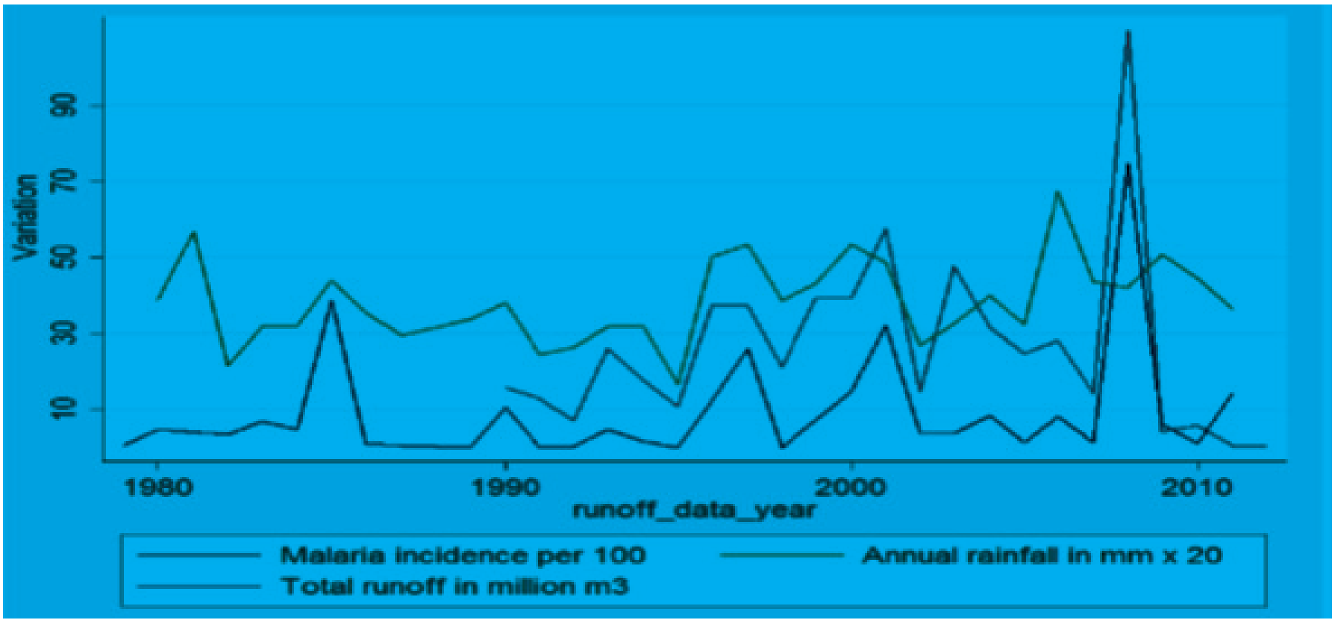
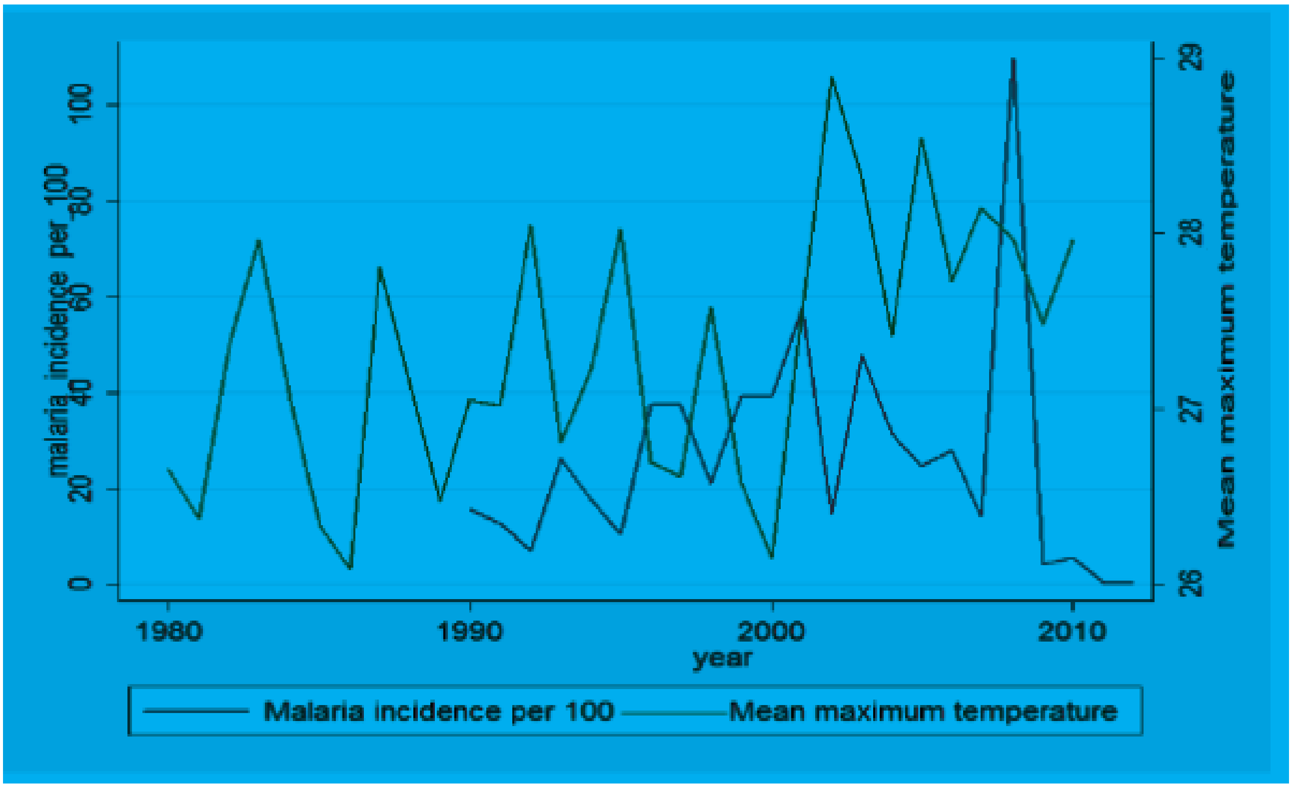


Figure 5 : The relationship between malaria incidences and mean monthly maximum temperature



3.3 Responses to malaria outbreaks

Malaria prevention and control in Zimbabwe dates back to the 1940s and has focused on prevention, early diagnosis and prompt treatment and surveillance (Mabaso et al., 2006; Ministry of Health and Child Welfare, 2009). All control measures in rural Zimbabwe since 1949 have been directed at the vector mosquitoes by means of spraying residual applications of insecticides, which kills mosquitoes when they come into contact with treated surfaces (Freeman, 1993).

The key malaria prevention, control and management strategies emphasized in the National Malaria Prevention and Control Policy (2003) include indoor residual spraying (IRS), use of insecticide treated nets (ITNs), malaria case management using effective diagnostics and life-saving drugs – artemisinin-based combination therapy - as well as monitoring and information raising (Ministry of Health and Child Welfare, 2009). Notable achievements regarding malaria control in Zimbabwe since the policy launch include the coming in of the Roll Back Malaria (RBM) initiative in 2007 and supported by the World Health Organization (WHO). The roll-back malaria initiative is a global strategy to reduce the burden of malaria through provision of resources and monitoring of progress on the tar2 gets (Mufunda et al., 2007). As part of the national malaria control campaign, run by the Ministry of Health and Child Welfare, Gokwe North has a malaria control programme, which has trained local health workers and distributed malaria prevention products.

Malaria surveillance is a critical element of malaria control. Since 1994, weekly malaria surveillance have been conducted and reported in weekly billeting at the national centre (Ministry of Health and Child Welfare, 2011). Currently no climate projections are considered, and thus the capacity for early detection and development of malaria early warning systems has not been used (Grover-Kopec et al., 2006). The only early warning system in operation uses rainfall time-series graphs based on recent rainfall, as opposed to future projections.

4.0 Conclusion and recommendations

Both cases in this paper have used modelling approaches, supplemented with document review and primary data collection at community level, in order to empirically assess the linkages between climate variables and meningitis and malaria. The most significant climatic factors in the emergence and resurgence of epidemic meningitis in the northern region of Benin are the decline in rainfall and relative humidity, which was widely endorsed by both communities and public health professionals.

In Zimbabwe hydro-climatic variables were fluctuating with temperatures showing a warming trend, whilst rainfall and surface runoff declining. Malaria incidences in the district inconsistently fluctuated following the variations and trends in hydro-climate variables. Incidences of malaria and surface runoff were perennial, suggesting warming winter temperatures could be contributing to increasing malaria incidences in the district.

The linkages between climate variables and these two diseases both highlight the potential for improved consideration of climate variables in surveillance systems, as well as the integration of future climate projections into epidemiological models in order to more effectively predict prevalence and outbreaks within the context of a changing climate (Abeku et al., 2004; Cox and Abeku, 2007; Da Silver et al., 2007). Currently there is no early warning system for meningitis in Benin, and the one in Zimbabwe is limited due to being based on recent-historical rainfall time-series data. More effective and integrated disease surveillance and early warning, in turn, is a prerequisite for improved prevention of, and preparation for, disease outbreaks, offering the opportunity to reduce mortality and morbidity (Abeku et al., 2004). However, in order for this to be achieved, health services need better information on accurate malaria and meningitis–climate projection models (Da Silver et al., 2007). This information can come from other sectors outside health, such as meteorology and environment. There may be scope for use of satellite rainfall forecasts into regional models, particularly with meningitis.

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